REPORT NO. FAA-RD-74-195.II

ASDE-2 RELIABILITY IMPROVEMENT STUDY
Volume II: Modulator, Receiver and Indicator Interface Recommendations

David N. Grover
C. Norman Butler

NOVEMBER 1974

FINAL REPORT

Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research and Development Service
Washington DC 20591

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-RD-74-195.II		

4. Title and Subtitle ASDE-2 RELIABILITY IMPROVEMENT STUDY Volume II: Modulator, Receiver and Indicator Interface Recommendations	5. Report Date November 1974 6. Performing Organization Code
7. Author(s) David N. Grover, C. Norman Butler	8. Performing Organization Report No. DOT-TSC-FAA-74-4.II
9. Performing Organization Name and Address Texas Instruments, Inc.* Dallas TX	10. Work Unit No. (TRAIS) FA421/R4113 11. Contract or Grant No. DOT-TSC-445-2
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington DC 20591	13. Type of Report and Period Covered Final Report July 1972-March 1973 14. Sponsoring Agency Code

15. Supplementary Notes

*Under contract to: U.S. Department of Transportation
Transportation Systems Center
Kendall Square
Cambridge MA 02142

16. Abstract

Eight airport sites and the FAA Oklahoma Depot were visited and surveys conducted to obtain reliability, maintainability and performance data on the ASDE-2 Radar System. The data was analyzed and recommendations for modification to the equipment made based on cost/benefit trade-offs. Three electronic modifications were recommended: modulator, local oscillator, and solid state duplexer modifications. (These modifications have since been accomplished.) To increase the operational utility of the ASDE-2 Radar, a bright display is recommended and, where space permits in the control tower, multiple displays.

The report contains detailed information on ASDE-2 reliability/maintainability, operational status, performance, and future ASDE system considerations as of March 1973.

The report is in two Volumes: Vol. I: Operational Data and Modification and Vol. II: Modulator, Receiver, and Indicator Interface Recommendations

17. Key Words	18. Distribution Statement
Airport Surface Detection Equipment (ASDE); Airport Surface Traffic Control; Radar (ASDE); ASDE-2 Reliability/Maintainability/Performance	DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	76	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

The ASDE-2 Reliability Improvement Study report was prepared by Texas Instruments Incorporated of Dallas, Texas under contract DOT-TSC-445, dated 20 June 1972, (completed 3/73) and is contained in two volumes as follows:

Volume I: Operational Data and Modification Recommendation;

Volume II: Modulator, Receiver and Indicator Interface Recommendations.

The principal objective of the study effort was to obtain reliability, maintainability, and performance data from ASDE-2 site visits, and based on an analysis of the site data, to recommend cost effective modifications to the equipment.

A secondary objective was to obtain information on the present and future desired control tower operational usage of the ASDE radar at each site.

The following sites were visited during the period from 7/72 to 9/72

New York (JFK)	Los Angeles
Newark	Seattle
Dulles	San Francisco
Andrews	Oklahoma City Depot
Chicago (O'Hare)	

Two-day visits were made to each site during which maintenance logs/records were recorded, maintenance and air traffic personnel interviewed and electronic and field (performance) test data taken.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1. INTRODUCTION

This report (Volume II) is submitted in completion of the requirements of contract DOT-TSC-445 and covers the tasks defined in items 4, 5 and 6 of the statement of work. Contract requirements defined in statement of work tasks 1, 2 and 3 are reported in Volume I of this report.

1.1 WORK REPORTED

The work reported in this volume consists of the following:

1. Modulator
   The ASDE-2 modulator section was analyzed by TSC to determine circuit modifications required to improve reliability. The TSC designed modulator modifications were reviewed. A cost benefit analysis was performed.

2. Receiver
   An analysis of the ASDE-2 receiver section was performed to determine specification requirements necessary to achieve stated system performance for solid state or vacuum tube IF amplifiers. A cost-benefit trade-off was performed to determine the cost effectiveness of modifying the ASDE-2 to use a highly reliable solid state IF amplifier. In addition work was expanded to accomplish the following:
   1. Restore and maintain specified performance of the ASDE-2 vacuum tube IF and video amplifiers by performing analysis leading to the definition of test, alignment or modification procedures that can be performed in the field.
   2. Perform laboratory tests to verify feasibility of procedures.

3. Perform field tests at an ASDE-2 site to verify that testing and alignment can be effectively implemented.

3. Indicator Interface

The ASDE-2 indicator azimuth data interface was analyzed to determine specifications and circuit modifications required for reliable maintenance free operation. A cost-benefit analysis was performed to determine the cost effect of changing the rotating deflection coil of existing PPI's to a mechanically stationary deflection coil that is electronically scanned from synchro generated antenna position signals.

1.2 CONCLUSIONS

Conclusions resulting from performance and cost-benefit analyses of the ASDE-2 modulator, receiver and indicator are as follows:

Modulator

1. The existing ASDE-2 modulator has a MTBF of approximately 75 hours.

2. Highly cost effective reliability improvements can be achieved with the TSC designed modulator modifications.

   a. Modified modulator reliability is predicted to exceed 500 hours.

   b. Modified modulator maintenance costs result in a saving of $90,000.00 over the next four years.

Receiver

1. Modification of the ASDE-2 to accept a solid state IF amplifier is not cost effective.

2. The ASDE-2 receiver system, consisting of preamplifier, IF amplifier and video amplifier is degrading resolution performance.

3. Improved testing and alignment procedures can significantly improve the performance of the ASDE-2 IF amplifier.

4. ASDE-2 video amplifiers require modifications to achieve design consistancy and specified performance.

5. System performance improvements (in resolution and definition) cannot be expected unless IF amplifier testing and alignment procedures are performed as recommended in conjunction with the video amplifier modifications.

Indicator

1. It is not cost effective to change the azimuth data readout from a rotating deflection coil to a mechanically stationary, electronically scanned deflection coil.

2. The $MTBF_{HV/SC}$ of the deflection coil drive assembly is approximately 900 hours.

1.3 RECOMMENDATIONS

Recommendations based on the above conclusions are as follows:

1. Modulator

   Incorporate TSC designed modulator modifications as soon as possible to increase reliability and reduce maintenance costs.

2. Receiver System

a. Institute the recommended IF amplifier test and alignment procedures in conjunction with the recommended video amplifier modifications. This combined action will improve system bandwidth and range resolution.

b. Provision of test equipment is necessary to implement the recommendations of (a). Minimum requirement is for a 100 to 150 MHZ bandwidth oscilloscope to supplement the existing on-site equipment (Jerrold 900A, grid dip meter, attenuators and adapters).

3. Indicator Interface

No changes are indicated.

1.4 REPORT ORGANIZATION

The remainder of this report is divided into sections as follows:

2. Modulator Recommendations
3. Receiver Recommendations & Analysis
4. Indicator Interface
5. Summary

Major conclusions and recommendations for effort expended on statement-of-work tasks 4, 5 and 6 are summarized in the introduction. Section 3 includes a detailed analysis of distributed amplifiers, the ASDE-2 IF amplifier and the ASDE-2 video amplifier It also includes an analysis that relates system resolution to pulsewidth and bandwidth. Section 5 summarizes the results of this study in terms of major conclusions, recommendations, action now being taken and actions to be taken.

2. MODULATOR RECOMMENDATIONS

Transportation Systems Center has performed a detailed analysis and study of the ASDE-2 modulator to determine cost effective modifications that can significantly improve transmitter reliability. The results of that study are presented in a TSC report dated June 1972. The modified modulator MTBF should be in excess of 500 hours judging by experience with modifications installed in the Logan and Kennedy ASDE-2's.

A cost impact analysis was performed in Volume I (pages 66 and 67) which shows that the TSC modification is cost effective with the cost breakeven point being reached in approximately five (5) months. Savings in maintenance costs of approximately $90,000.00 are predicted over the next four years.

If modulator modifications are implemented prior to receiver modifications the system $MTBF_{HV/SC}$ can be expected to increase from 24 hours to 32 hours. Subsequent receiver modifications will then increase MTBF to approximately 80 hours as reported in Volume I, figures 2-4 and 3-2.

The TSC designed modulator modification has been reviewed. It is recommended that this modification be incorporated in all ASDE-2's because of the following:

1. It is a low cost means to greatly increase the reliability of the modulator.

2. It is estimated that the MTBF of the modulator will be increased from 75 to 500 hours by the incorporation of this modification

3. The improvements offered by solid state or magnetic modulators would not be cost effective for the intended period of use of three to five years.

3. RECEIVER RECOMMENDATIONS

It was shown in Volume I of this report that the incorporation of a solid state IF amplifier would not be cost effective. The effort expended as part of contract statement-of-work item 5 was therefore redefined with the objective of improving the performance of the ASDE-2 receiver and associated circuits to obtain specified performance. Specifically the following tasks were addressed:

1. The receiver IF and video amplifiers were analyzed to determine specifications and tuning and alignment procedures and modifications that will help improve the ASDE-2 range resolution.

2. A more detailed cost-benefit trade-off analysis was performed to verify and complete the results shown in Volume I.

3. Testing and alignment procedures were conceived for the IF amplifiers; laboratory tests showed that significant performance improvements could be achieved in IF amplifier gain and bandwidth.

4. The test and alignment procedures were then tried on the San Francisco International Airports'ASDE-2. IF amplifier improvements were made; the improvements were observable at the remote site PPI console. These improvements in display clarity and sharpness were not observable on the ASDE-2 BRITE TV monitor in the ATC tower building equipment room. The ASDE-2 BRITE implementation limitations are discussed in paragraph 3.3.2.

3.1 ASDE-2 RECEIVER DESCRIPTIONS

The purpose of this section is to provide an overview of the complete ASDE-2 receiving system including interfaces and to discuss the status of the receiver in terms of performance and reliability.

The block diagram of figure 3-1 includes the receiver and receiver interfaces that can be affected by modifications or replacements of subassemblies. The descriptions in this section are similar to those of reference [1] but are provided here for completeness and convenience. The receiving system receives radar return signals from the RF feed system, amplifies these signals in the pre-amplifier and IF amplifier, and defects and filters them in the detector stage to provide video to the indicators. The video amplifiers in the indicators are considered part of the complete receiver system for the considerations of this section.

Referring to the block diagram, there are three separate functional groupings:

1. RF section
2. IF section
3. Video Distribution Drivers

The RF section consists of the mixer, local oscillator, a.f.c. and IF preamplifier. The output of the RF section is an IF signal with a bandwidth of 100 MHZ centered at 130 MHZ. The gain of the IF preamplifier is 8 dB minimum. The frequency of the local oscillator is maintained at a difference of 130 MHZ with respect to the transmitter frequency by the a.f.c circuit.

The IF amplifier consists of 9 gain stages and one detector stage; each stage is mechanized using seven tubes in a distributed amplifier configuration. The IF amplifier has a bandwidth (two-sided) of 100 MHz and a gain in excess of 80 dB. A selectable FTC circuit

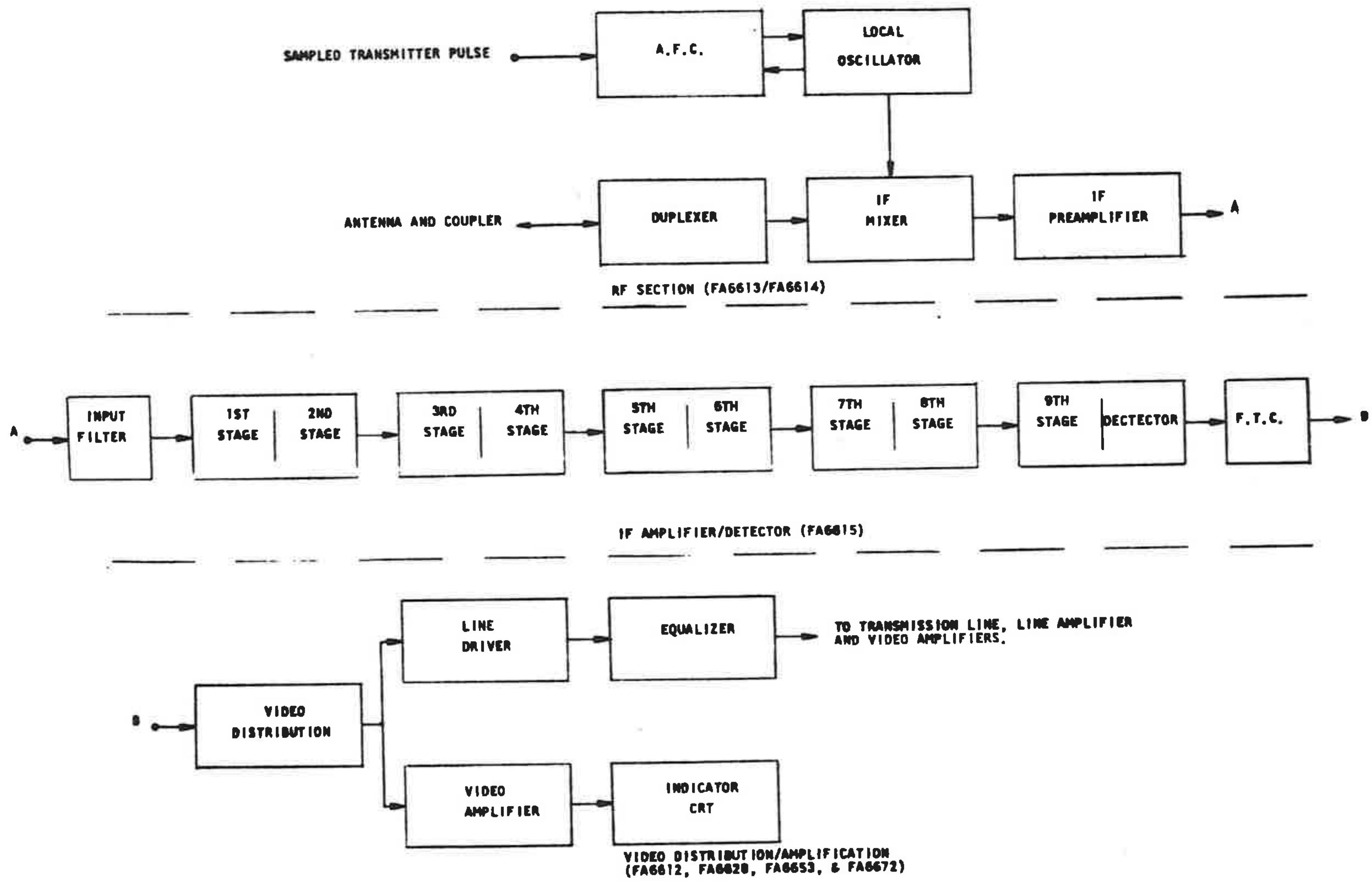


FIGURE 3-1: ASDE-2 RECEIVER AND RECEIVER INTERFACE BLOCK DIAGRAM

is also provided to differentiate signals to shorten the longer pulses; this prevents stronger signals from blocking weaker targets.

Distribution drivers consist of the video distribution amplifier, line drivers, equalizers, line amplifiers and video amplifiers. The video distribution amplifier has a specified bandwidth of 50 MHz and a gain of 3.5 dB. The line driver has a specified bandwidth of 60 MHz and a gain of 17 dB. The equalizer permits selection of 13 different equalizing functions to properly compensate remoting lines. Video amplifiers in the PPI consoles have a specified bandwidth of 50 MHz and a gain of 30 dB. Video signals to the cathode of the CRT will typically be 10 to 80 volts peak depending on target strength, and display settings.

The poor quality of the ASDE-2 display presentations, manifested by poorly defined targets, background and movement areas can generally be attributed to poor radar resolution, jitter and to inadequate display parameters. Poor range resolution can be caused by inadequate bandwidth of the receiver and video amplifiers. A lack of target definition can also be caused by inadequate gain of the receiver-video amplifier chain; the smaller signal returns from target peripheries (such as wing tips) that are needed to clearly define target edges will not be amplified sufficiently. A radar with poor range resolution but with adequate gain will tend to clearly define target edges in azimuth but smear target edges in range. A radar with low gain and narrow bandwith will tend to smear target edges both in azimuth and in range. This later situation essentially describes the general quality of ASDE-2 displays that were observed during site surveys and visitations.

3.2 SOLID STATE I F AMPLIFIER CONSIDERATIONS

It was shown in Volume I of this report that the ASDE-2 IF amplifier contributes 3.9% of the single channel failures and that replacement with a solid state IF amplifier would result in a system $MTBF_{HV/SC}$ improvement of 13 hours and a $MTBM_{HV/SC}$ improvement of 6 hours. It was also estimated that the implementation cost for eight sites would be $26,000 and that the net cost increase of the solid state IF amplifier would be $10,000 for all eight sites over the next five years; this is for development, parts and direct labor. A detailed cost-benefit trade-off is made in paragraph 3.2.2.

It is expected that a performance improvement in IF amplifier bandwidth and gain would be masked by limitations of the IF preamplifier, video distribution and video amplifiers. Significant overall performance improvements can be expected only by attention to improvement of all signal amplification and distribution subassemblies.

3.2.1 Specification Requirements

The specification requirements for a replacement solid state IF amplifier are essentially the same as they are for the existing ASDE-2 IF amplifier. Table 3-1 lists the specification requirements for an exact replacement solid state IF amplifier. These requirements are easily within the state-of-the-art for a solid state amplifier. Several factors should be considered prior to deciding to use a solid state IF amplifier. These are:

1. The STC function may be more effectively implemented by using PIN diode attenuators in the waveguide before the preamplifier or IF amplifier. This approach is advantageous

TABLE 3-1

SOLID STATE IF AMPLIFIER
SPECIFICATION
REQUIREMENTS

PARAMETER	VALUE
BANDWIDTH (3 db points)	100 MHz MIN
CENTER FREQUENCY	130 MHz
GAIN	80 dB MIN
NOISE FIGURE	19 dB MAXIMUM (RECEIVER)
STC	30 - 40 dB (VARIABLE 4th POWER CURVE)
VIDEO GATE	DISCONNECT DURING TRANSMIT
GAIN CONTROL	20 TO 40 dB - MANUALLY ADJUSTABLE

because the crystals will not saturate and the STC waveform is more completely decoupled from the I.F. signals.

2. The center frequency of the solid state I.F. amplifier may be advantageously moved to a lower or higher frequency.

   A lower frequency (near 60 MHz) permits mechanization with non-critical circuitry and simpler maintenance. Achievement of wide bandwidths at these frequencies with solid state amplifier is well within the state-of-the-art.

   A higher frequency (near 500 MHz) permits the use of conventional tuned circuits to achieve the 100 MHz bandwidth, however stripline techniques or cavity mechanizations will be necessary. An added advantage of the higher frequency I.F. amplifier implementation is that the larger difference frequency permits waveguide filtering to reject image frequency responses. Elimination of image responses permits an improvement of up to three (3) dB in signal-to-noise ratio over lower center frequency IF amplifier configurations.

3. A change of the ASDE-2 IF amplifier center frequency will also require a change in the AFC circuitry. This must also be considered as a major factor.

4. The effect of a greatly improved IF amplifier on overall bandwidth, gain and resolution must be determined to assure that anticipated improvements are actually achievable. Bandwidth requirements are discussed further in the analyses of section 3.3.

   A typical solid state IF amplifier having gain, bandwidth and other parameters generally adequate to meet the specification requirements of table 3-1 is shown in figure 3-2. Interface modifications would also be necessary to assure proper power supplies, bias voltages and gain controls prior to change over. Complete drawings and schematics are not provided since the application of a solid state IF amplifier is not cost effective and therefore has not been recommended or proposed.

3.2.2 COST BENEFIT TRADE-OFF

A cost benefit trade-off has been made to determine the cost impact of using the existing ASDE-2 IF amplifiers and the costs to change over to a solid state replacement IF amplifier.

The costs of using the existing ASDE-2 IF amplifiers are shown in Table 3-2. The costs include both scheduled and unscheduled replacement of tubes and are broken down into categories of parts and labor. Over the next five year period a cost of $16,375.00 is estimated.

The costs of changing over to a solid state IF amplifier are shown in Table 3-3. The costs include implementation costs consisting of development, parts and labor and the yearly maintenance costs of the solid state IF amplifier. Over the next five years a cost of $26,600.00 is estimated.

Figure 3-3 shows the cost impact of a solid state IF amplifier. A net cost of $10,000.00 results after five years of use of the solid state IF amplifier. Since the costs will not breakeven until after eight years of use, a change to solid state IF amplifiers is not recommended.

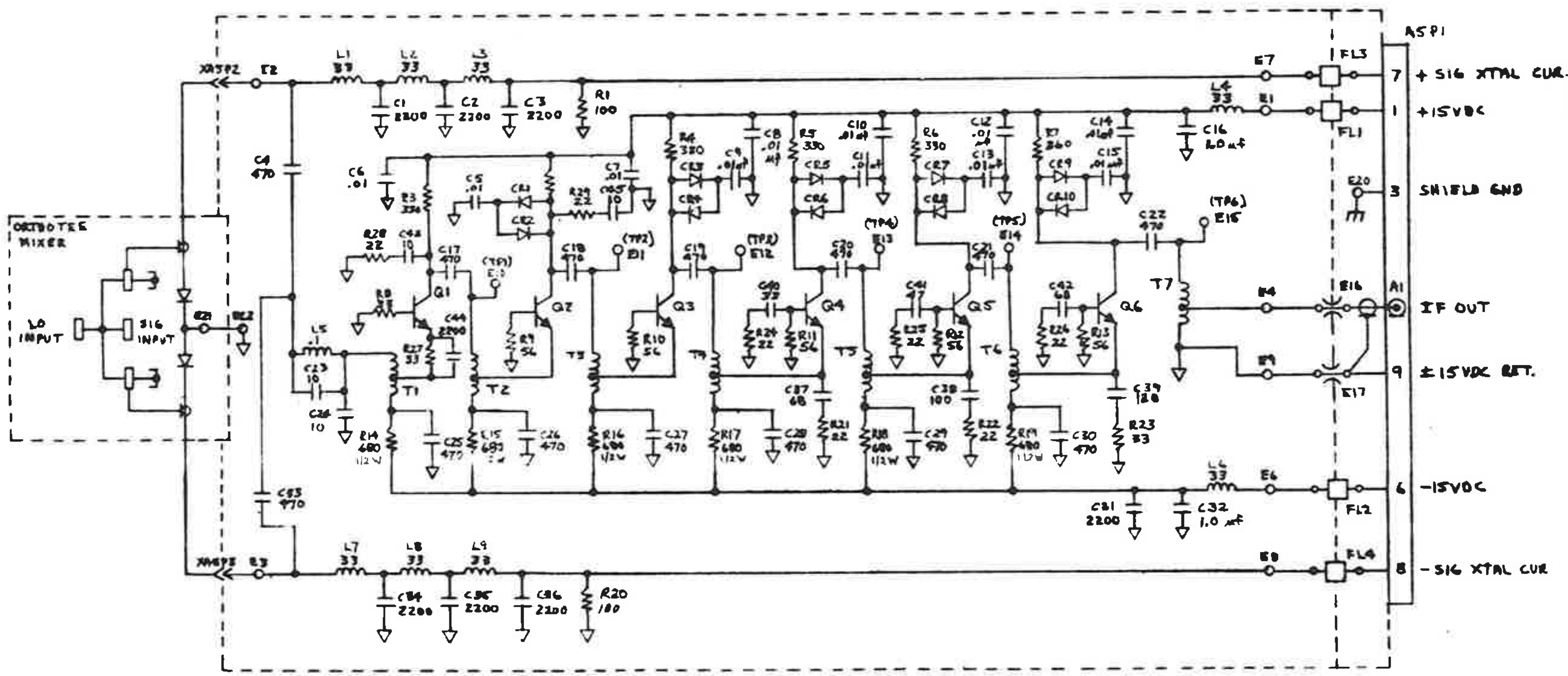


FIGURE 3-2: SOLID STATE IF AMPLIFIER PART A - PREAMPLIFIER SECTION

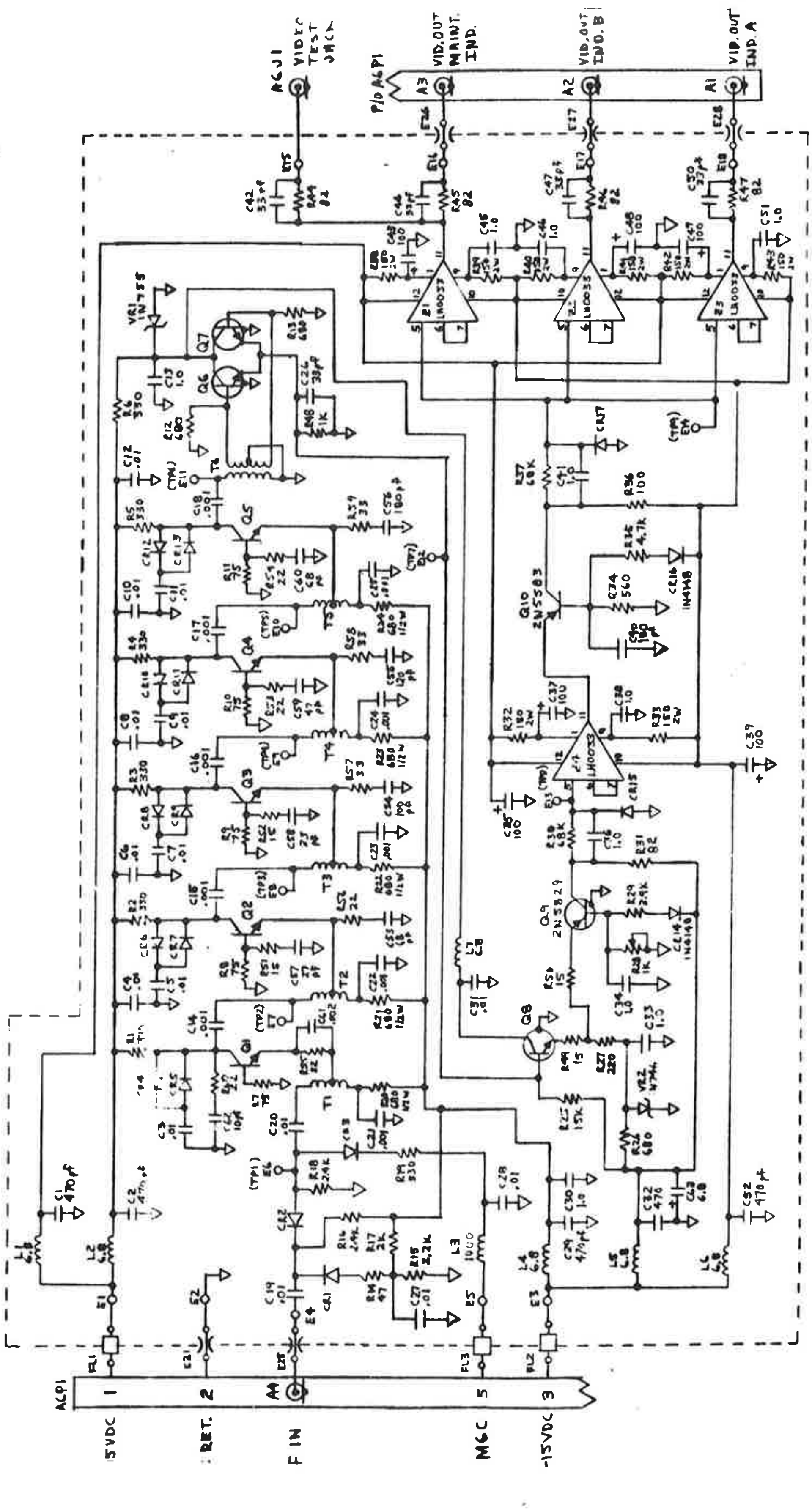


FIGURE 3-2: SOLID STATE IF AMPLIFIER PART B - DETECTOR

TABLE 3-2 COST OF EXISTING ASDE-2 IF AMPLIFIERS

A. Unscheduled replacement of 6AK5's $517/year

1. Parts - 300/year @ $1 = $300/year
2. Labor - (.085 Hrs) X (300/year) X ($8.50/Hr) = $217/year

B. Replacement of 6AK5's during quarterly tube checks $2760

1. Parts - 1600/year @ $1 = $1600/year
2. Labor - (.085 Hrs) X (1600/yr) X ($8.50/Hr) = $1160/year

TOTAL COST OF USING EXISTING ASSEMBLY ≈ $3,275/year

TABLE 3-3 COST OF NEW SOLID STATE IF AMPLIFIERS

A. Implementation cost $26,000

   1. NRE cost - $6,000

   2. Parts & Labor - (1,250/channel) X 16 channels) = $20,000

B. Yearly maintenance cost $120/year

   - based on 1.2 failures per year at cost to repair of $100/ failure assuming:

     - 14,800 HV operate hours/year

     - solid state IF amplifier and pwr supply failure rate of 80×10^{-6} failures/hour

TOTAL COST OF USING SOLID STATE AMPLIFIERS ≈ $26,000 + $120/yr

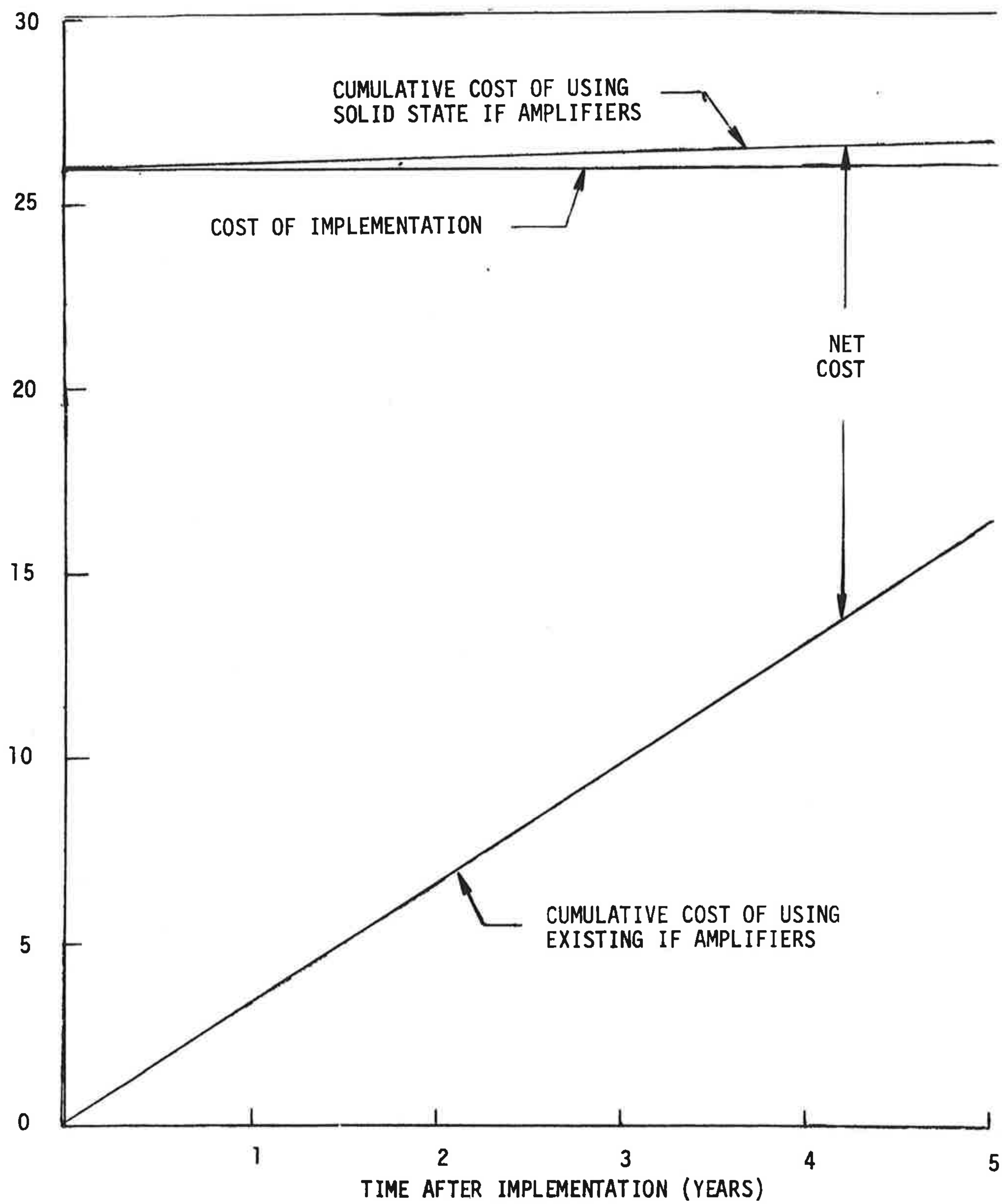


FIGURE 3-3

COST IMPACT OF A SOLID STATE IF AMPLIFIER

3.3 ANALYSES

Distributed amplifiers are analyzed to determine if the ASDE-2 IF and video amplifiers are capable of meeting specification requirements. It was also a purpose of the analysis to gain insight about the designs such that alignment and test procedures could be formulated that would help restore the ASDE-2's to specified performance levels. An analysis is also included that relates required system bandwidth to pulsewidth and range resolution.

3.3.1 Generalized Distributed Amplifiers

A generalized five section distributed amplifier stage is shown in figure 3-4. It consists of coupling networks (C) that couple the input signal from the source to the distributed amplifier and from the amplifier to the load; input and output delay elements (D_i and D_o) that delay the input and output signals equally; load elements (L) that terminate the delay lines in the correct impedance to maximize gain and to minimize reflections and ringing; and gain elements (G) that amplify the input signals.

A properly operating distributed amplifier delays the input signal as it travels down the input or grid delay line such that it reaches the input of each gain element sequentially. The gain elements amplify the input signals causing a current to flow in the output delay line. The delays of each section of the input and output delay lines are adjusted to be identical. When these conditions are met, all the currents which reach the output line coupling and load arrive at the same time and are added. That is, the gain of each section of a distributed amplifier adds linearly to the overall stage gain.

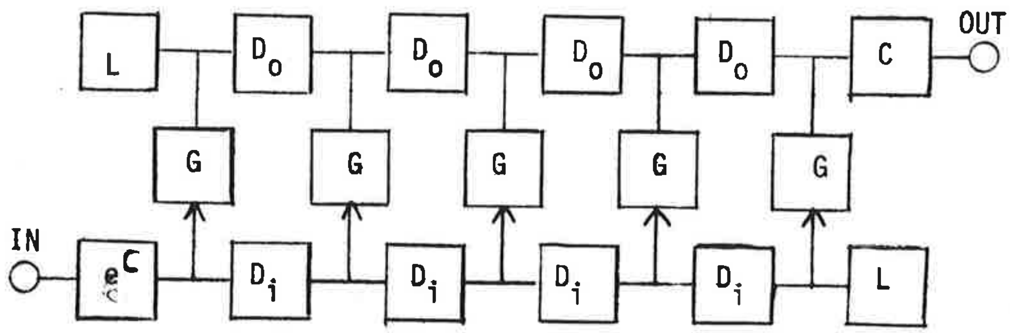


FIGURE 3-4

GENERALIZED DISTRIBUTED AMPLIFIER

Following the discussion of reference [2] an implementation of a distributed amplifier using pentode vacuum tubes is shown in figure 3-5. The capacitances C_g and C_p represent, respectively, the input and output capacitances of the tubes together with the stray or any other capacitances present. The capacitances and inductances make up the delay lines; the resistors provide line terminations. The grid and plate lines have characteristic impedances (R_o) given by the following formulas:

$$R_{og} = \sqrt{\frac{L_g}{C_g}} \qquad \text{(Grid)}$$

$$R_{op} = \sqrt{\frac{L_p}{C_p}} \qquad \text{(Plate)}$$

The gain (A) of a distributed amplifier (or stage) having n sections (tubes) is given as (reference [2])

$$A = \frac{1}{2}\, n\, g_m\, R_{op}$$

The gain of a stage from grid line to the following grid line requires an impedance transformation from the impedance of the plate line (R_{og}) to the impedance of the grid line (R_{og}) in the ratio $(R_{og}/R_{op})^{1/2}$. Then

$$A = \frac{n\, g_m}{2}\, R_{op}\sqrt{\frac{R_{og}}{R_{op}}} = \frac{n\, g_m}{2}\sqrt{R_{op}\, R_{og}}$$

The cutoff frequency of the amplifier may be considered to be determined by the cutoff frequency of the delay lines. The cutoff frequencies of the grid and plate lines are the same since the delay per section is the same for both lines. The cutoff frequency (f_c) for a delay line is given as

$$f_c = \frac{1}{\pi \sqrt{LC}}$$

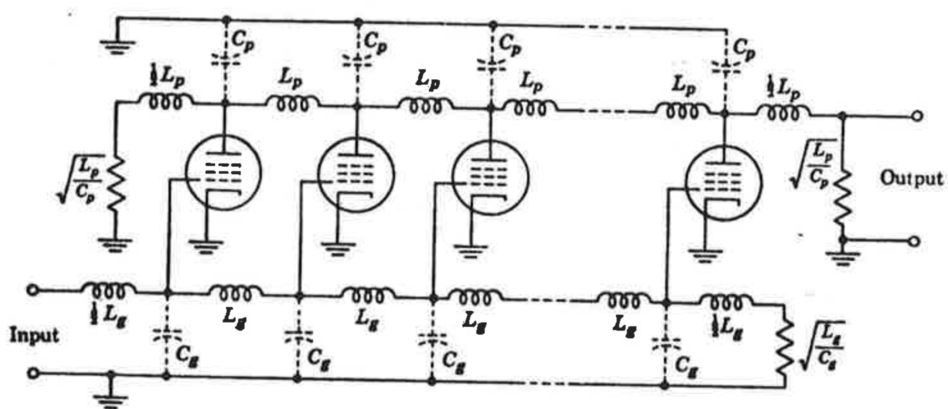


FIGURE 3-5: DISTRIBUTED AMPLIFIER STAGE

The bandwidth of a multiple stage amplifier f_{cs} is reduced (reference [2]) according to the equation,

$$f_{cs} = (f_c)\left(\frac{1}{\sqrt{m}}\right)$$

A delay line is characterized by the nominal characteristic impedance (R_o), the total delay (t_d) and the risetime (t_r) of the output for an ideal step input.

The time delay per section of the delay line is given as

$$t_s \doteq \frac{1}{\pi f_c} = \sqrt{LC}$$

The total delay of n sections is simply

$$t_d = nt_s$$

It has also been shown in reference (2) that the experimentally determined risetime (t_r) of n sections is equal to the cube root of n times the risetime (t_{r1}) of a single section, and that the risetime of a single section is given by

$$t_{r1} = 1.13 \sqrt{LC}$$

Then,

$$t_r = \sqrt[3]{n}\ 1.13 \sqrt{LC}$$

These relationships are used to determine the design consistency, gain and bandwidth of distributed amplifiers.

3.3.2 Analysis of ASDE-2 IF Amplifier

The ASDE-2 IF amplifier is analyzed to determine design parameters and capabilities. A stage of the ASDE-2 IF amplifier consists of 7 sections (tubes) and is schematically shown in the circuit of figure 3-6. Values of components and circuit descriptions of the implementation are as follows:

1. The amplifier stage uses seven 6AK5 pentode vacuum tubes with a transconductance (g_m) of 5000μ mhos.

2. The grid line parameters are taken as follows:

   C_g = 5.0 pf

   (4.0 pf grid capacitance,
   1.0 pf stray capacitance)

   L_g = 0.33 μh

3. The plate line parameters are taken as:

   C_p = 5.0 pf

   (2.8 pf plate capacitance,
   2.0 pf capacitor, 0.2 pf stray
   capacitance)

   L_p = .33 μh

4. Load terminations are as follows:
   Grid line - 240 ohms
   Plate line - 280 ohms

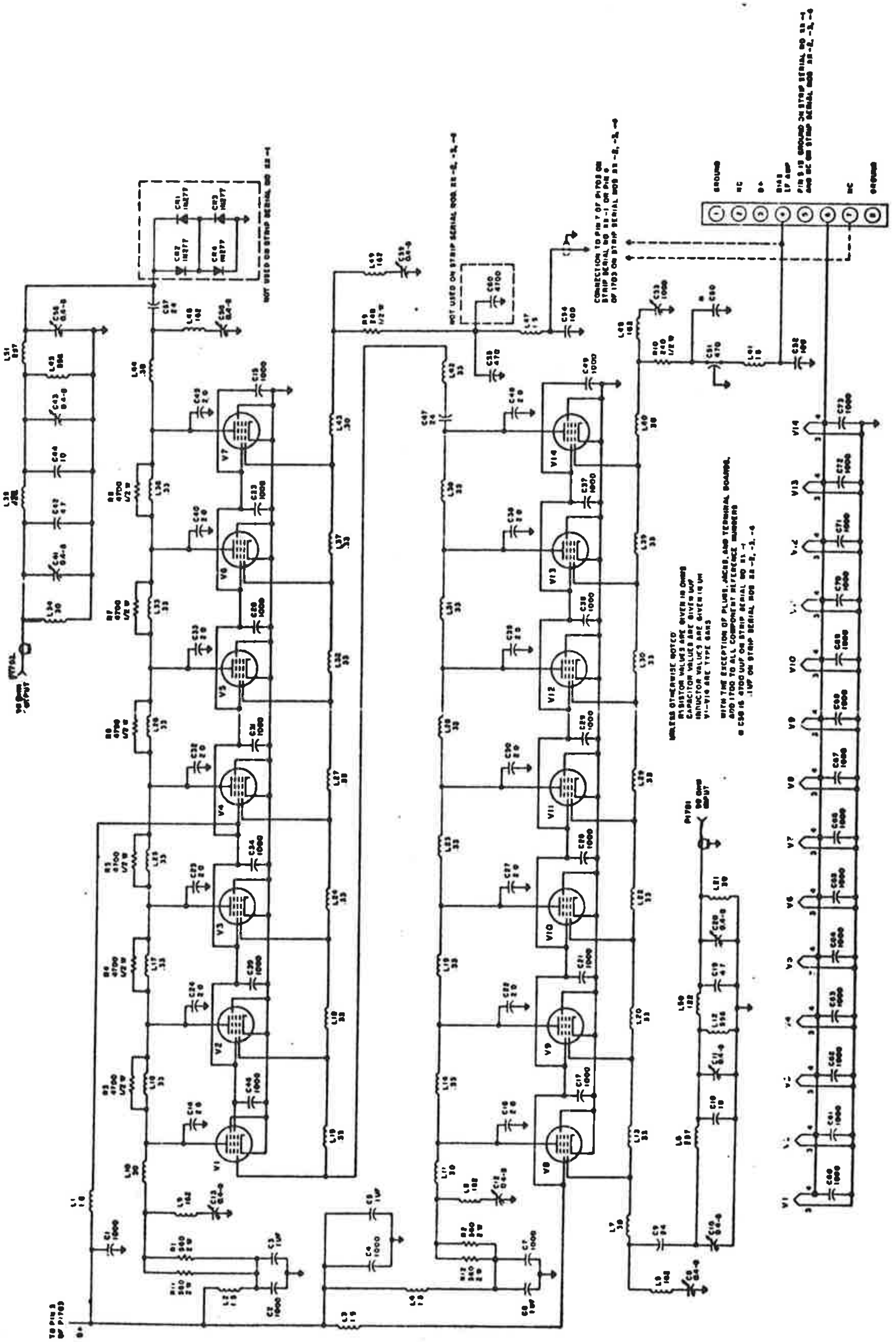


FIGURE 3-6: ASDE-2 IF AMPLIFIER

Calculations of characteristic impedance, delay times, bandwidth and gain are performed to determine design consistency.

Characteristic impedances of the grid and plate lines are determined to be

$$R_{og} = \sqrt{L_g/C_g} = 256 \text{ ohms}$$

$$R_{op} = \sqrt{L_p/C_p} = 256 \text{ ohms}$$

Delay times of each stage (7 tubes) can then be calculated to be

$$t_d = 7\sqrt{LC} = 7(1.28)\text{ns} = 9.0 \text{ ns}$$

Bandwidth or cutoff frequency of the seven tube stage is given by the following:

$$f_c = \frac{1}{\pi\sqrt{LC}} \doteq 250 \text{ MHz}$$

The bandwidth of the ten stage IF amplifier will be reduced according to the $1/\sqrt{n}$ formula to approximately 80 MHz for the ten stage IF amplifier. This results in a one sided or video bandwidth of approximately 40 MHz.

The gain of an IF amplifier stage is calculated as follows:

$$A = \frac{ng_m}{2} \sqrt{R_{og} R_{op}}$$

or

$$A = \frac{(7)(5000)(256)(10^{-6})}{2} = 4.1$$

or

$$A = 20 \log_{10} (4.1) = 12.2 \text{ dB}$$

The gain of the first nine stages of the IF amplifier is then approximately 110 dB. The tenth or detector stage then is therefore not required to provide gain.

3.3.3 Analysis of ASDE-2 Video Amplifier

The ASDE-2 video amplfier will now be analyzed to determine design parameters and capabilities. The video amplifier (figure 3-7) is an eight section distributed amplifier that drives the cathode of the indicator CRT. Circuit descriptions and component values are as follows:

1. The video amplifier uses eight 6AH6 pentode vacuum tubes with a transconductance of 9000 μ mhos

2. The grid line parameters are taken as follows:

   C_g = 21 pf
   (10 pf input capacitance,
   10 pf capacitor, 1 pf stray
   capacitance)

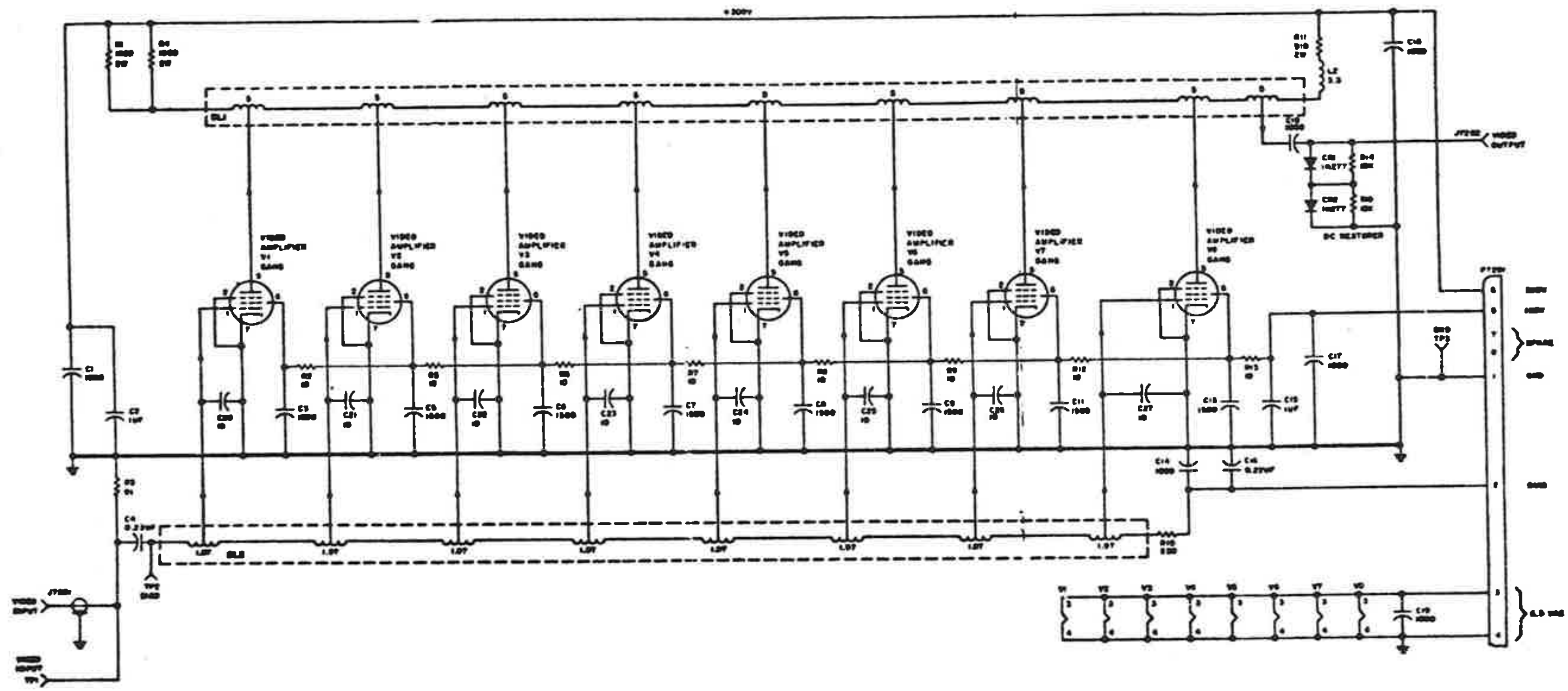


FIGURE 3-7: ASDE-2 VIDEO AMPLIFIER

$L_g = 1.97\ \mu h$

3. The plate line parameters are taken as follows:

$C_p = 3$ pf
(2 pf output capacitance,
1 pf stray capacitance)

$L_p = 5\ \mu h$

4. Load terminations are as follows:

Grid line = 220 ohms
Plate line = 900 ohms

Calculations of characteristic impedances, delay times, bandwidth and gain can now be performed to determine design consistency.

Characteristic impedances are:

$$R_{og} = \sqrt{L_g/C_g} = 302 \text{ ohms}$$

$$R_{op} = \sqrt{L_p/C_p} = 1290 \text{ ohms}$$

Delay times of each line can be calculated as follows:

$$t_{dg} \doteq 8\sqrt{L_g C_g} = (8)(6.42 \text{ ns}) = 51.4 \text{ ns}$$

$$t_{dp} = 8\sqrt{L_p C_p} = (8)(3.88) = 31.0 \text{ ns}$$

The grid line delay is 1.65 times longer than the plate line delay. This is a serious discrepancy that cannot be rectified by small changes in assumed values of stray capacitance. To increase the delay of the plate line to equal that of the grid line for proper operation of the distributed amplifier requires an increase of the total plate capacitance to 8.25 pf. Conversely, if the grid line delay were to be reduced to match that of the plate line, we find that the total grid capacitance would have to be 7.6 pf which is less than the tube capacitance. In the following we calculate results, as far as possible, for both lines.

Bandwidth, or cutoff frequency of the lines, is calculated as follows:

$$f_{cg} = \frac{1}{\pi\sqrt{L_g C_g}} = \frac{1}{\pi\,(6.42X10^{-9})} = 49.5 \text{ MHz}$$

$$f_{cp} = \frac{1}{\pi\sqrt{L_p C_p}} = \frac{1}{\pi\,(3.88X10^{-9})} = 82 \text{ MHz}$$

The gain of the video amplifier can be calculated as follows:

$$A = \frac{ng_m}{\quad} \sqrt{R_{og}\, R_{op}}$$

or

$$A = \frac{(8)(9000)(625)(10^{-6})}{2} = 22.5 \quad (27 \text{ dB})$$

The existing video amplifier does not meet the requirements of design consistency since the delays of grid and plate lines are not identical, it does not have specified bandwidth or gain. It will be necessary to modify or replace the video amplifier to be able to meet the minimum specification requirements. It is recommended that the video amplifiers be modified as described in the following paragraph.

3.3.3.1 Modification of ASDE-2 Video Amplifier

A design modification can be made on the video amplifier by removing the 10 pf grid capacitors, adding 1.5 pf plate capacitors, changing the grid load resistor to 430 ohms and the plate load resistors to 1000 ohms.

The delay line parameters are then;

C_g = 11 pf (10 pf + 1 pf stray); L_g = 1.97 μh

C_p = 4.3 pf (2 pf + 1 pf stray); L_p = 5 μh

The characteristic impedances of the delay lines can then be computed to be;

$$R_{og} = \sqrt{L_g/C_g} = 444\ \Omega$$

$$R_{op} = \sqrt{L_p/C_p} = 1075\ \Omega$$

The delay times of both the grid and plate lines is;

$$t_{dv} = 8\sqrt{L_g C_g} = 8\sqrt{L_p C_p}$$

$$= (8)(4.65\ \text{ns}) = 37.2\ \text{ns}$$

Bandwidth of the delay lines is;

$$f_c = \frac{1}{\pi\sqrt{L_g C_g}} = \frac{1}{\pi\ (4.65\ \text{ns})} = 68.5\ \text{MHz}$$

Gain of the modified video amplifier is;

$$A_m = \frac{ng_m}{2} \sqrt{R_{og}\ R_{op}}$$

or

$$A_m = \frac{(8)(9000)(690)(10^{-6})}{} = 24.8$$

or

$$A_m = 20\ \log_{10}\ (24.8) = 28\ \text{dB}$$

This design for a modified video amplifier meets the requirements for design consistency and has adequate bandwidth. The gain is not significantly improved and does not meet the 30 dB requirement shown in SMP 6330.1, however it will be adequate.

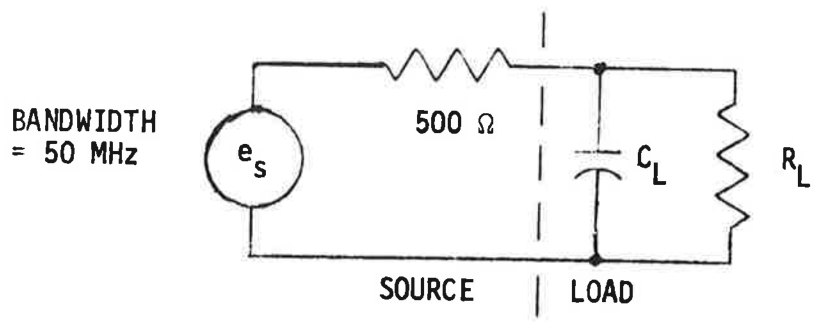
3.3.3.2 Video Amplifier Loading

It is important to consider the effect of loading on the ASDE-2 video amplifier since improper loading can greatly reduce bandwidth. The output impedance is approximately 500 Ω, and the equivalent signal source can be considered to have a bandwidth of fifty megahertz. The equivalent circuit is shown in figure 3-8. If the load resistance (R_l) is greater than 5K Ω, then the R-CL circuit configuration has the following transfer function:

$$\frac{eo}{ei} = \frac{1}{1 + j\ \omega CR}$$

We can calculate the maximum value of capacitive loading that can be tolerated by the video amplifier to achieve various 3 dB bandwidths. The bandwidths and maximum permissable load capacitances are as follows:

10 MHz with 31.8 pf;
20 MHz with 15.9 pf;
30 MHz with 10.8 pf;
40 MHz with 8.0 pf;
50 MHz with 6.4 pf;



C_L is the load capacitance

R_L is the load resistance

FIGURE 3-8: VIDEO AMPLIFIER OUTPUT LOADING

Typical indicator CRT's present capacitive loads of 3 to 6 pf for cathode inputs. This, added to stray capacitance which depends on layouts and wire lengths will typically limit this circuit to bandwidths less than 30 MHz. (Approximately 10 pf total)

If the video output is routed over coaxial cable as it is in the ASDE-2 BRITE conversions, we must consider the effect of cable capacitance. This must be a primary consideration since the cable is not terminated in it's characteristic impedance. Special low-capacitance coax will have a minimum of 5 or 6 pf per foot, however, typical good quality low capacitance cable will have approximately 10 pf of capacitance per foot. Using this later value we can estimate the bandwidth of the video amplifier with 12 foot of cable to be approximately 2.5 MHz. This is an extremely serious degradation and a correction is recommended. A simple modification can be effected by relocating the video amplifier for the 5" PPI such that an unshielded wire run of only one to two feet is necessary between the video amplifier and the CRT cathode. The input to the video amplifier uses wideband terminated coaxial cable that will not be degraded by any additional cable length necessary for relocation.

3.3.4 Distributed Amplifier Analysis Data Summary

Table 3-4 presents a summary of analysis data used to analyze the ASDE-2 IF and video amplifiers; it includes the results of an analysis of a recommended modification of the video amplifier.

TABLE 3-4. SUMMARY OF DISTRIBUTED AMPLIFIER ANALYSIS DATA

DISTRIBUTED AMPLIFIER COMPONENTS & PARAMETERS	IF AMPLIFIER		VIDEO AMPLIFIER		MODIFIED VIDEO AMPLIFIER	
	SPECIFICATION	CALCULATED	SPECIFICATION	CALCULATED	SPECIFICATION	CALCULATED
BANDWIDTH						
STAGE		250 MHz	50 MHz	49.5 MHz	50 MHz	68 MHz
OVERALL	50 MHz min.	80 MHz	50 MHz	49.5 MHz	50 MHz	68 MHz
GAIN						
STAGE		12.2 dB	30 dB	27 dB	30 dB	28 dB
OVERALL	80 dB min.	110 dB	30 dB	27 dB	30 dB	28 dB
VACUUM TUBES						
NUMBER, TYPE	70, 6AK5	-	8, 6AH6	-	8, 6AH6	-
Cin, Cout	4 pf, 2.8 pf	-	10 pf, 2 pf	-	10 pf, 2 pf	-
TRANSCONDUCTANCE (g_m)	5000 μ mho	-	9000 μ mho	-	9000 μ mho	-
DELAY LINES						
GRID: CAPACITANCE (TOTAL)	5.8 pf	-	21 pf	-	11 pf	-
INDUCTANCE	.33 μh	-	1.97 μh	-	1.97 μh	-
LOAD RESISTOR	240 Ω	-	220 Ω	-	440 Ω	-
CHARACTERISTIC IMP.	-	256 Ω	-	302 Ω	-	444 Ω
STAGE DELAY TIME	-	9.0 ns	-	51.4 ns*	-	37.2 ns
PLATE: CAPACITANCE (TOTAL)	5.8 pf	-	3 pf	-	4.3 pf	-
INDUCTANCE	.33 μh	-	5 μh	-	5 μh	-
LOAD RESISTOR	280 Ω	-	900 Ω	-	1075 Ω	-
CHARACTERISTIC IMP.	-	256 Ω	-	1290 Ω	-	1075 Ω
STAGE DELAY TIME	-	9.0 ns	-	31.0 ns*	-	37.2 ns

* NOTE: THESE ENTRIES INDICATE A DESIGN INCONSISTENCY.

3.3.5 System Bandwidth Requirements

The purpose of this section is to derive overall video bandwidth (BW) requirements of radar systems in terms of range resolution (ΔR) and pulsewidth (t_w).

Resolution is defined as the ability of a radar to separate closely spaced targets; it can be approximated, in feet, as one-half the pulse separation period (T) when T is expressed in nanoseconds. It has been assumed that the overall system bandwidth is determined by a predominant single pole filter: sharper filter rolloffs will only make small changes in results.

The pulses on line (a) of figure 3-9 have a pulsewidth t_w and represent returns from point targets that are separated by a radar time delay (T). The pulses on line (b) represent the filtering effects of the receiver and video amplifier on the pulses of line (a). The variation (e_v) of the filtered signal is not equal to the full amplitude (A) of the signal because of the close spacing of the returns and the 'filter' response time. The Rayleigh resolution criteria requires a minimum signal variation of 3 dB to separate closely spaced targets of equal amplitude on A scope presentations. Considering the PPI display, large signal dynamic ranges, high brightness environments and response of the eye a minimum signal variation of 12 dB will be required to resolve (separate) targets in operational usage conditions.

The response of a single pole filter to the ideal input pulse shown in figure 3-9 is given by the equation

$$A = A_{max} \quad (1-e^{-t/\tau})$$

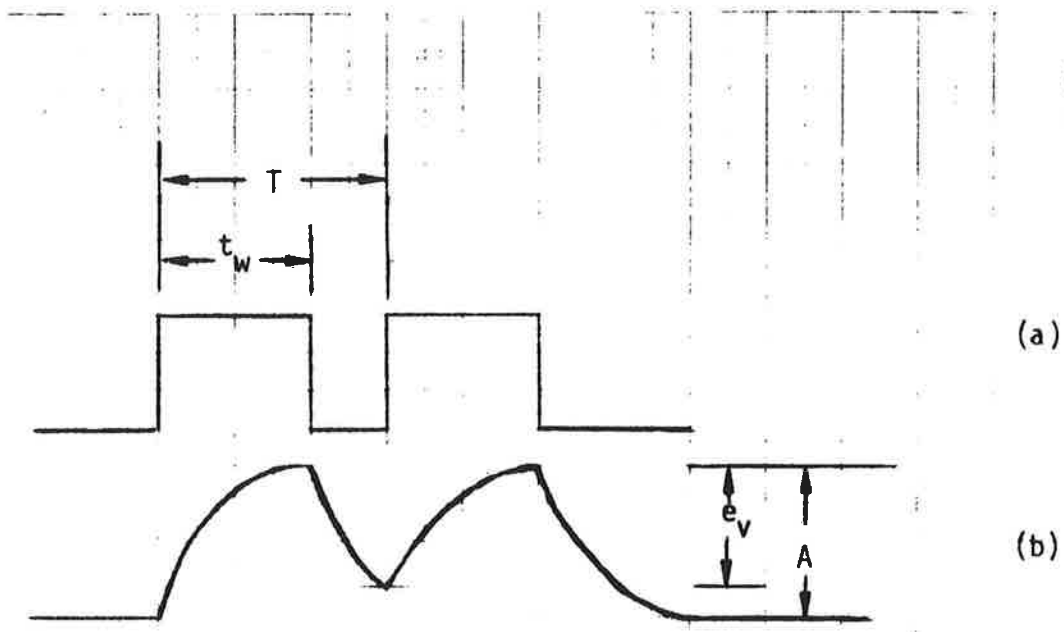


FIGURE 3-9: EFFECT OF SYSTEM FILTERING

(a) IDEAL INPUT PULSES

(b) FILTERED PULSES AT OUTPUT

It is shown in reference [2] that the risetime (t_r) is related to the bandwidth (BW) as follows:

$$t_r = \frac{.35}{BW} = 2.2\ \tau$$

The response of the filter or system to an input pulse of sufficent width, for a given bandwidth, will stabilize at the value A_{max}. It is necessary for the value of A to reach approximately 0.9 A_{max} to assure that radar performance is not significantly degraded; using the above equations, this requires a pulsewidth

$$t_w \geq \frac{.35}{BW} .$$

If the pulsewidth is less than specified by the above equation a reduction occurs in signal amplitude which causes a degradation in signal-to-noise ratio. Before making conclusions, consider the variation in the output signal amplitude that occurs during the period $(T - t_w)$. For the required 12 dB signal amplitude variation the value of e_v (figure 3-9, line b) equals .75A. From the above equations we find this variational requirement is achieved if $(T - t_w) = .221/BW$.

Then, the resolution period is given as

$$T = t_w + \frac{.221}{BW}$$

where T and t_w are in microseconds and BW is in MHz

Since $t_w \geqslant \frac{.35}{BW}$, we can also find the limit

$$T \geqslant \frac{.57}{BW} \quad \text{(microseconds).}$$

The system resolution is given as

$$\Delta R = 500 \left(t_w + \frac{.221}{BW}\right) \qquad \text{(feet)}$$

$$\Delta R > \frac{285}{BW} \qquad \text{(feet)}$$

This is plotted in figure 3-10, in terms of resolution (in feet) as function of pulsewidth (in nanoseconds) for various bandwidths. The curves are shown only for the ranges of pulsewidths for which the 12 dB criteria is met. The dotted line joins points of minimum pulsewidths. If a radar has pulsewidths and bandwidths that place its operating point to the left or above the dotted line it will suffer degradation due to reduced signal amplitude and reduced signal-to-noise ratios; the display will lack contrast and clarity, definition of targets and overall appearance will be poor. Figure 3-10 can be used to determine the bandwidth requirements for general high resolution, narrow pulsewidth radars.

It must be remembered that the above derivation is performed for ideal pulses and signal pole filters to provide useful approximations. If the received pulse risetimes are one-half or less of the risetime corresponding to bandwidth of the circuit (t_{rc} = .35/BW), the bandwidth requirement will be

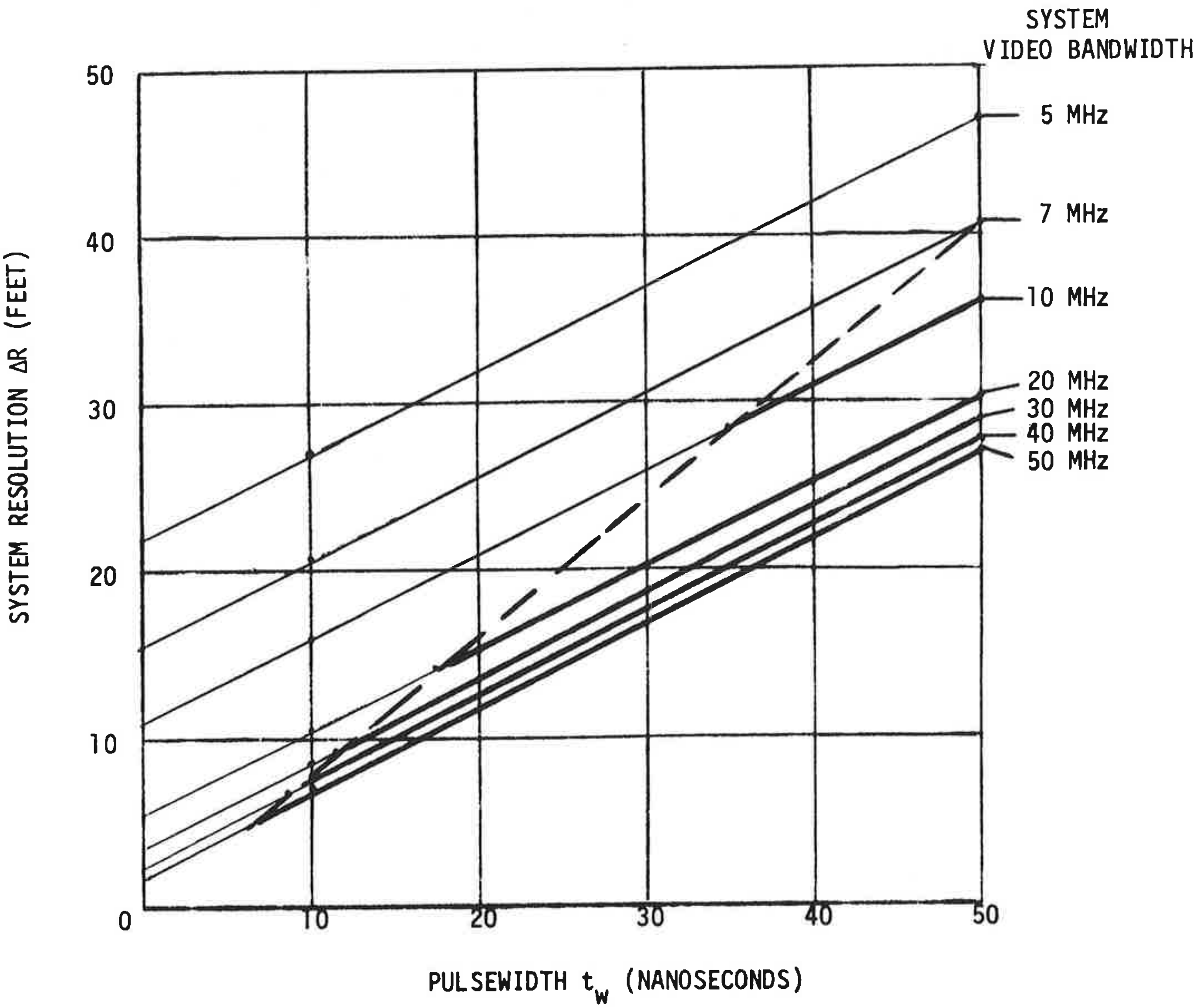


FIGURE 3-10: RESOLUTION CAPABILITY - IDEAL RADAR

increased by approximately fifteen percent. For example, a required 35 MHz system bandwidth will be achieved with a transmitted pulse risetime of 5 ns if the receiver-video amplifier combined bandwidth is approximately 40 MHz. These factors must be considered to assure meaningful calculations of system bandwidth requirements; additionally the effects of jitter and signal-to-noise ratios must be included to complete the analysis.

We can now consider the bandwidth of the ASDE-2 receiving system that is shown in block form in figure 3-1. By specification, as summarized in SMP 6330.1, the 3 dB bandwidths of the series units are as follows:

IF Preamplifier	100 MHz (two sided)
IF Amplifier	100 Mhz (two sided)
Video Distribution & STC	50 MHz
PPI Video Amplifier	50 MHz

The 3 dB bandwidth of the line driver that is used in some configurations for interfacing with up to 6000 feet of video cable is 60 MHz.

If the ASDE-2 is performing to specification the combined bandwidth of the IF preamplifier and IF amplifier is 35 MHz. The combined bandwidth of the video distribution and STC and the PPI video amplifier is also 35 MHz. The overall bandwidth of all four series amplifiers is 24.8 MHz. When a line driver is used the overall bandwidth reduces to 22.8 MHz. Comparing these results with the requirements imposed by the graph of figure 3-10 we find that the ASDE-2 is analytically capable of achieving a resolution of approximately 16 feet. Considering degrading influences and band limited signals we estimate an actual attainable resolution of approximately twenty-five feet.

Bandwidth (B) for the cascaded amplifiers was determined as follows:

$$B = \frac{.35}{t_{rs}}$$

where

t_{rs} is the risetime of the combined amplifiers.

t_{rs} is computed as follows:

$$t_{rs} = t_{r1}^2 + \ldots + t_{ri}^2 + \ldots + t_{rn}^2$$

where t_{ri} is the risetime of the i^{th} stage of n total stages.

$$t_{ri} = \frac{.35}{BW_i}$$

and finally BW_i is the bandwidth of the i^{th} amplifier.

3.4 IF AMPLIFIER ALIGNMENT PROCEDURES

Tests performed during the operational site surveys reported in Volume I indicated that system bandwidths were narrower than specification. While video amplifiers are one major cause of reduced system bandwidth, improvements in IF amplifiers can result in a significant improvement in receiver performance. Reduced IF amplifier bandwidths and gain in operational ASDE-2's are apparently a result of are or more of the following factors:

1. Maintenance procedures which exist are general in nature and do not specify minimum levels of performance that are acceptable.

2. Maintenance personnel do not have test equipment that is adequate for testing and alignment.

3. Variations in the quality of 6AK5 vacuum tubes can cause noticable changes in the IF amplifier performance.

The purpose of this section then is to discuss existing and new procedures for alignment and test of IF amplifiers.

3.4.1 Existing Procedures

The existing procedures for alignment of the IF preamplifier and the IF amplifier are detailed in section 7, paragraph 4.1.4 of the ASDE-2 Instruction Book, Volume I. This is a step by step procedure that gives the sequence of adjustments necessary to align the IF amplifier. In one step it lists eight variable capacitors that are to be tuned "for the flattest response between 80 and 180 MHz". There are four more variable capacitors that influence the tuning and alignment that are not included. From this we conclude that existing procedures are not adequately detailed for the complexities of the distributed IF amplifier. It is recommended that the alignment procedure be expanded to include more detail in procedures and indications of minimum acceptable or average attainable performance. These points are described in the recommended alignment procedures of paragraph 3.4.2.

3.4.2 Recommended Preamplifier and IF Amplifier Alignment Procedure

The following procedure is similar in form and sequence to the existing procedure, however it has been expanded to include additional detail and clarifications. Test Equipment required for alignment consists of a Jerrold 900A, a 150 MHz bandwidth oscilloscope*, attenuators, a grid-dip meter and various circuit adapters.

---

* Tektronix Model 454 or equivalent

PREAMPLIFIER and IF AMPLIFIER ALIGNMENT PROCEDURE

a. Remove the cover from the preamplifier

b. Remove receiver crystals CR1303 and CR1304

c. Connect the output of the sweep generator to the input of the preamplifier through an attenuator and an adapter.

NOTE

Before connecting the sweep generator calibrate it to sweep from 80 to 180 Mc. Refer to the handbook supplied with the sweep generator for calibration instructions.

d. Remove the first strip from the IF amplifier and insert the strip adapter in its place.

e. Connect the output of the strip adapter to the input of the oscilloscope and adjust the scope gain and the attenuator at the input to the preamalifier for the best presentation.

f. Adjust C1315, C1318 and C1319 in the preamplifier and C1622, C1623 and C1626 in the input filter for the flattest response between 80 and 180 MHz. Variations of up to 3 dB are acceptable.

g. Remove the second IF strip and replace the first IF strip. Insert the strip adapter in place of the second IF strip.

h. Adjust the scope gain and the attenuator for the waveform of about 0.3 volt on the oscilloscope.

i. Adjust C20, C11, C10, C8 C53, C12, C59, C13, C56, C58, C43 and C41 for the flattest response between 80 and 180 MHz.

NOTE

Alignment will be simplified by recognizing certain groupings of the tuning capacitors. Refer to figure 3-11 for location of tuning capacitors on the IF strips. The function of each capacitor is shown in table 3-5. The tuning and alignment procedure, to achieve the flattest response is as follows:

1. Reduce the capacitance of all "trap" (table 3-5) capacitors by backing out capacitor slugs five to ten turns. This reduces roll offs that may restrict amplifier bandwidth.

2. Tune input filter capacitors for maximum flatness.

3. Tune output filter capacitors for maximum flatness.

4. Retune "trap" capacitors until their effect is observed.

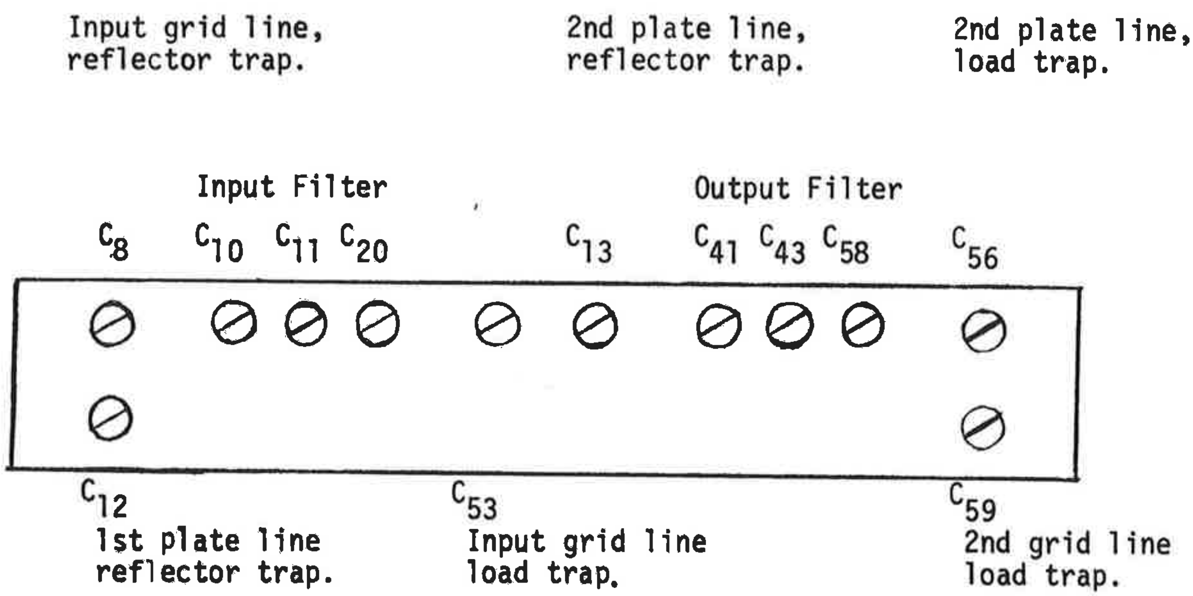


FIGURE 3-11: IF STRIP TUNING CAPACITOR LOCATIONS

TABLE 3-5: IF AMPLIFIER TUNING CAPACITOR FUNCTIONS

CAPACITOR DESIGNATION	FUNCTION OR LOCATION
C20 C11 C10	Input filter
C58 C43 C41	Output filter
C8	Input grid line - reflector trap
C53	Input grid line - load trap
C59	2nd stage grid line - load trap
C12	1st stage plate line - reflector trap
C13	2nd stage plate line - reflector trap
C56	2nd stage plate line - load trap

j. Remove the third strip and replace the second IF strip. Insert the strip adapter in place of the third IF strip.

k. Adjust the IF gain of the receiver and the input attenuator for a waveform of about 0.3 volt on the oscilloscope.

l. Repeat step i using the capacitors on the second strip.

m. Remove the fourth IF strip and replace the third strip. Insert the strip adapter in place of the fourth IF strip.

n. Repeat steps k and l except insert 'third strip' for 'second strip'.

o. Remove the fifth strip and replace the fourth IF strip. Insert the strip adapter in place of the fifth IF strip.

p. Repeat steps k and l, but insert 'fourth strip' for 'second strip'.

q. Replace the fifth strip.

r. Remove the input to the FTC box (J1619) on the IF amplifier and connect the IF output adapter to plug removed (P1619).

s. Connect the output of the adapter to the oscilloscope.

t. Adjust the scope gain, IF gain, and input attenuator for a waveform of about 4.0 volts in amplitude. The IF gain should be adjusted so that there is not excessive noise on the waveform.

u. Adjust C1520, C1511, C1510, and C1508 for the flattest response between 80 and 180 Mc. These have the same function as those on the IF amplifier strips.

It is recommended that the IF amplifier alignment be refined, until the overall passband variations, as measured in step u, are held to a maximum of six (6) dB; if this flatness is not achievable record frequency ranges where variations exceed 6 dB.

3.4.3 Laboratory Tests

Measurements were made in the laboratory to determine gain and bandwidth of IF and video amplifiers.

An IF amplifier furnished by TSC was tested, as received, prior to any adjustments or tuning. A summary of IF amplifier gain and bandwidth is presented below:

The IF amplifier, as received, had an overall gain of 90dB, with contributions from individual IF strips as follows:

Strip 1	- 15 dB
Strip 2	- 22 dB
Strip 3	- 20 dB
Strip 4	- 19 dB
Strip 5	- 14 dB

The bandwidth of the IF amplifier was approximately 60 MHz (video bandwidth of 30 MHz)

Tubes were tested on a Hickok model 1700 laboratory type tube tester. The results of these tests is shown as a distribution in figure 3-12.

Since new 6AK5's were not available the fourteen tubes that met the specification were substituted in the first IF strip. Tests showed that the IF strip gain was increased to 22 dB with variations of less than 4 or 5 dB for a bandwidth of 120 MHz.

Lack of a source of 6AK5's prevented testing of the complete IF amplifier in the laboratory, however it was concluded that the use of more detailed alignment procedures would be helpful in improving receiver performance.

3.4.4 On Site Tests

Measurements and alignment procedures were attempted on-site with the SFO ASDE-2 IF amplifier. The purpose of this testing and alignment was to determine if the procedures would be effective in restoring specified receiver performance.

The IF amplifier of channel B was used for tests. Initial tests indicated the passband had amplitude variations of approximately 12 to 15 dB and the higher end (150 to 180 MHz) was severely attenuated.

Tubes were tested and the poorer tubes were replaced.

The 6AK5 tubes were tested with the on-site, Hickok model 752 tube tester which does not have a standard transconductance scale. To report standard values a tube was tested on both the Hickok model 752 and the 1700 model and readings were linearly scaled. The

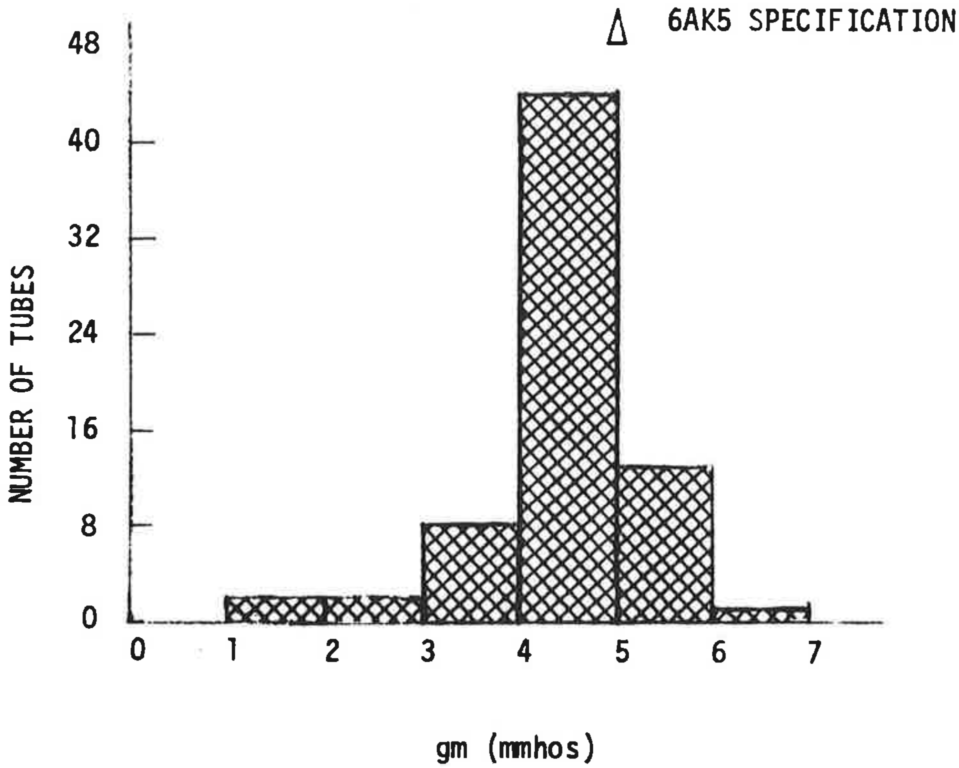


FIGURE 3-12: DISTRIBUTION OF gm OF 6AK5's IN TSC FURNISHED IF AMPLIFIER

distribution of g_m of 6AK5's in the SFO IF amplifier is shown in figure 3-13.

The alignment procedure was performed. The result of several iterations of the procedure in paragraph 3.4.2 was as follows:

1. Gain increased by approximately 10 dB.

2. IF bandwidth increased by 20 to 30 MHz, on the high end, approaching the specification.

3. PPI display at the remote radar site had several noticeable improvements;

    a. The background areas were better defined - apparently due to stronger signals and wider bandwidth.

    b. Target shapes appeared to be better - wings were painted on Boeing 727's and 737's which hadn't been as well defined prior to tuning and alignment.

    c. Contrast improved - most likely due to stronger signals.

4. The BRITE TV display in the AFS equipment room did not appear to be improved. This most likely due to limitations of system bandwidth in the BRITE system PPI video amplifier as discussed in section 3-3. The tower cab BRITE was not observed.

It is recommended that the procedure of section 3.4 be implemented as part of a program to improve performance of the receiver and video amplifiers. If other system limitations are not corrected the IF amplifier bandwidth improvement resulting from implementation of the procedures of paragraph 3.4.2 will most likely be masked.

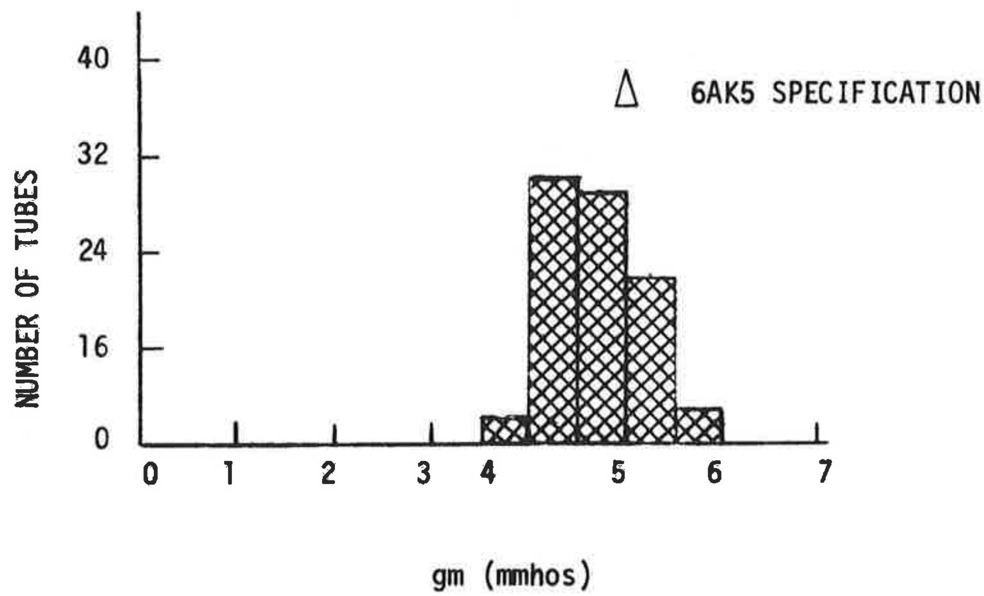


FIGURE 3-13: DISTRIBUTION OF gm OF 6AK5's IN SFO IF AMPLIFIER

REFERENCES

1. Instruction Book:
   Airport Surface Detection
   Equipment Model ASDE-2, type FA 6600

2. Millman & Taub, Pulse Digital and
   Switching Waveforms, McGraw Hill
   Book Company, New York, 1965.

4. INDICATOR INTERFACE

Problems that have been experienced with the deflection assembly were shown to constitute 2.6 percent of the single channel system failure rate in Volume 1 of this report. Corrective actions taken to improve the reliability of the azimuth sensor, after corrections to improve reliability of all other assemblies with higher failure rates, will only increase system $MTBF_{HV/SC}$ by 11 hours.

4.1 DESCRIPTION OF ASDE-2 INDICATOR INTERFACE

The ASDE-2 PPI console azimuth readout is implemented as shown in the block diagram of figure 4-1. An alternator geared to the antenna drive shaft provides a signal of approximately 4 volts amplitude and 75 Hz that is amplified by the servo amplifier to power the synchronous deflection coil drive motor. This maintains synchronism between the display rotational rate and the antenna rotational rate. Since the initial position of the display and antenna can be different, it is necessary to be able to correct the orientation of the display to correspond to that of the antenna. Corrections are made to the mechanical position of the rotating deflection yoke at the rate of 4 degrees per antenna revolution by an operation of a correction motor and a mechanical differential that drives the yoke assembly gear train. Signals to the correcting motor are derived from cam operated position contractors on the antenna and deflection coil assembly. The timing signals shown in figure 4-2 are used to illustrate the correction process. The antenna switches close for 173° out of 360° of antenna rotation and are arranged such that one or the other of the switches are closed except for two arcs of 1° and 13° where both switches are open. Relay driver logic generates

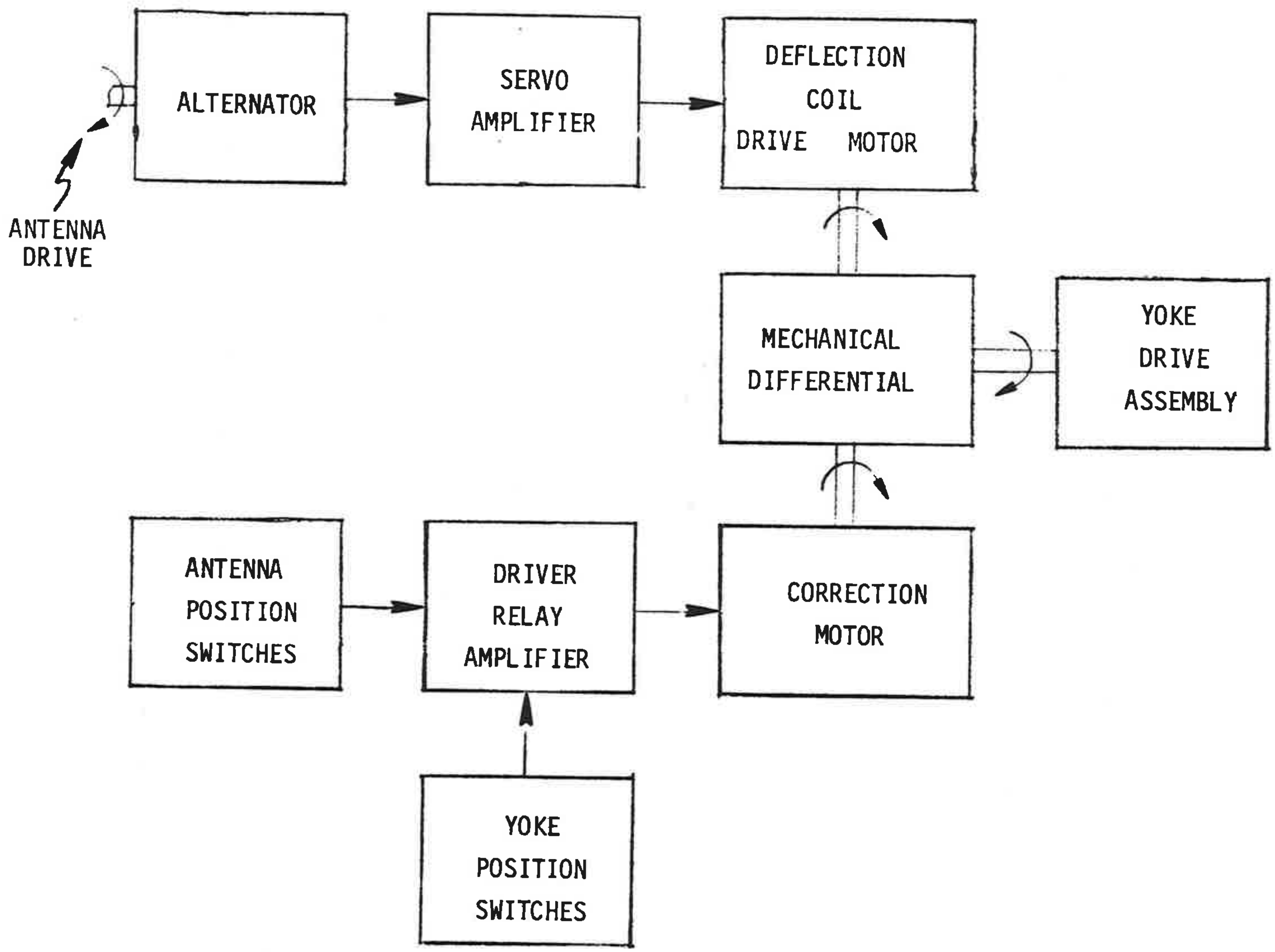
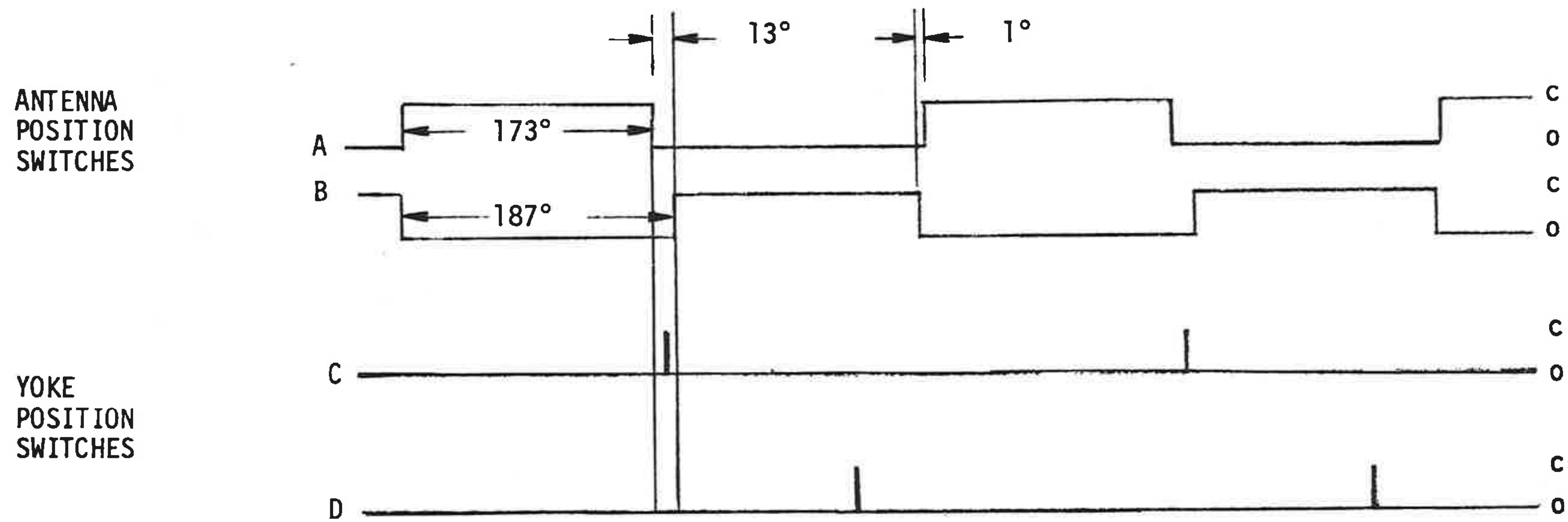


FIGURE 4-1. ASDE-2 INDICATOR AZIMUTH INTERFACE



NOTE: C INDICATES CONTACT CLOSURE; O INDICATES CONTACT OPEN

FIGURE 4-2. ASDE-2 AZIMUTH CORRECTION TIMING signals that power the correction motor as follows:

1. Yoke phase is advanced by 4° when the A switch is closed at the time of the yoke sample pulse (C).

2. Yoke phase is retarded by 4° when the B switch is closed at the time of the yoke sample pulse (C).

3. Yoke phase is not changed when both the A and B switches are open at the time of the yoke sample pulse (C).

4. When the advance or retard signals are applied to the correction motor, they are removed after 120° of antenna rotation by the grounding signal (D). The one degree period where both switches are off is less than the sample pulsewidth, therefore hangups will not occur.

4.2 COST BENEFIT TRADE OFF

The estimated cost impact of replacing the rotating deflection coil in the ASDE-2 PPI with a mechanically stationary deflection coil is determined in this section. The synchro azimuth sensor system was chosen as a model since its costs are low and its reliability high. Costs to modify each indicator are detailed in section 4.3.

Table 4-1 shows the costs of using the existing deflection drive assembly and the costs of modifying all 17 [(1)] indicators. The

---

(1) Seven sites have 2 PPI displays, one site (LAX) has three indicators. Some are in 5" PPI's used in the ASDE-2 BRITE conversions.

TABLE 4-1. COST IMPACT - INDICATOR AZIMUTH INTERFACE

A. Cost of existing deflection drive maintenance at all eight sites.

Deflection coil drive assemblies
17 units per year @ $400.00 ea = $6800.00

B. Cost of changing to a synchro sensing stationary deflection coil system for all 17 indicators.

NRE	$40K
Subassembly Parts & Labor $1450.00 X 17, approximately	$24K
Installation $.425K X 17, approximately	$ 7K
Total Modifications	$71K

Yearly Maintenance costs are negligible

breakeven point occurs at over ten (10) years. This modification is not considered cost effective and is not recommended.

4.3 AZIMUTH READOUT MODIFICATIONS

Several different approaches can be considered to modify the azimuth readout of the ASDE-2 to eliminate the rotating deflection yoke. Each approach is similar in that they all require a change over to a two coil deflection yoke with independent sweep generation circuitry for each coil. The sine and cosine information required to electronically scan the indicator in synchronism with the antenna can be obtained by use of synchro resolvers geared to the antenna drive shaft. Alternately, an antenna change pulse (ACP) system can be used that provides count pulses and reference pulses from sensors geared to the antenna shaft. This latter approach is a digital implementation which requires conversion to obtain horizontal and vertical deflection signals; it is most advantageously applied to systems that use digitized radar signals.

The cost of modifying the azimuth readout to a synchro azimuth-sensing system is estimated as follows for each indicator:

1. Yoke Assembly	$250.00
2. Yoke Drivers	$400.00
3. Integrators & Timing	$200.00
4. Power Supplies	$400.00
5. Synchro Demodulator	$200.00
Total Subassemblies	$1450.00

Design, development and documentation are estimated to require approximately 9 man months for a cost of $40K.

Installation costs are estimated for fifty hours per indicator because of the extensive modifications required. This applies only to dismantling the existing indicator, installing prefabricated assemblies and rewiring. This results in installation costs of $425.00 per indicator.

5. SUMMARY

This section presents a complete summary of the results of the ASDE-2 reliability improvement study program in terms of conclusions, recommendations, actions being pursued and actions to be taken. The purpose of the recommendations is to improve the reliability and performance of the ASDE-2 for an interim period until a new ASDE-type radar can be developed and deployed. Results of the study have been classified into the following four areas for convenience of discussion:

1. Reliability
2. Operational Procedures
3. Performance
4. Mechanization

5.1 CONCLUSIONS

The study resulted in the following conclusions:

5.1.1 Reliability [1]

1. The ASDE-2 average single channel MTBF for high voltage operation is 24 hours.

2. High incidence of distributed random failures prevents cost effective reliability improvement to MTBF's greater than 79 hours, under present usage conditions.

---

[1] See definitions of MTBF and MTBM on page 41, Vol. 1.

3. Significant cost effective reliability improvements can only be made to the modulator (FA-6618) and to the receiver (FA-6613).

4. Availability is high due to frequent maintenance and general low usage.

5. Maintenance costs are more directly related to filament operate hours than to high voltage operate hours.

5.1.2 Operational Procedures

1. Accessibility of the display to controllers determines the operational use. Accessibility is defined as a function of the number of displays, location of display(s) and brightness.

2. Limited usage is caused by poor performance - poorer performance then results in less usage establishing a cyclic degradation.

5.1.3 Performance

1. The ASDE-2 will not penetrate moderate to heavy precipitation due to backscatter.

2. Range resolution averages 2.2 times specification and azimuth resolution averages 1.36 times specification.

5.1.4 Mechanization

This paragraph relates to specific functions and subassemblies of the ASDE-2.

Modulator

1. The existing ASDE-2 modulator has a MTBF of approximately 75 hours.

2. Highly cost effective reliability improvements can be achieved with the TSC designed modulator modifications.

   a. Modified modulator reliability is predicted to exceed 500 hours.

   b. Modified modulator maintenance costs result in a saving of $90,000.00 over the next four years.

Receiver

1. Modification of the ASDE-2 to accept a solid state IF amplifier is not cost effective.

2. The ASDE-2 receiver system, consisting of preamplifier, IF amplifier and video amplifier, is degrading resolution performance.

3. Improved testing and alignment procedures can significantly improve the performance of the ASDE-2 IF amplifier.

4. ASDE-2 video amplifiers require modifications to achieve

design consistency and specified performance.

5. System performance improvements (in resolution and definition) cannot be expected unless IF amplifier testing and alignment procedures are performed in conjunction with the recommended video amplifier modifications.

Indicator

1. It is not cost effective to change the azimuth data readout from a rotating deflection coil to a mechanically stationary, electronically scanned deflection coil.

2. The $MTBF_{HV/SC}$ of the deflection coil drive assembly is approximately 900 hours.

5.2 RECOMMENDATIONS

Based on the above conclusions, the following recommendations are made:

5.2.1 Reliability

1. Incorporate TSC determined modulator modifications
2. Incorporate solid state duplexers
3. Incorporate solid state local oscillator on the merit of reliability improvement and relatively low cost.

5.2.2 Operational

1. Increase display accessibility by use of ASDE-2 BRITE modifications as an interim measure only. Multiple displays are recommended where space permits.

5.2.3 Performance

1. Conduct quantitative tests on an ASDE-2 antenna, weather penetration and beamwidth for azimuth resolution.

2. Increase bandwidth of receivers and video amplifiers for better range resolution. Relocate ASDE-2 BRITE system PPI video amplifiers as described in paragraph 3.3.3.

5.2.4 Mechanization

This paragraph contains recommendations concerning specific functions and subassemblies in the ASDE-2. The recommendations are as follows:

1. Modulator
Incorporate TSC designed modulator modifications as soon as possible to increase reliability and reduce maintenance costs.

2. Receiver System

a. Institute the recommended IF amplifier test and alignment procedures in conjunction with the recommended video amplifier modification.

   This combined action will improve system bandwidth and range resolution.

b. Provision of test equipment is necessary to implement the recommendations of (a). Minimum requirement is for a 100 to 150 MHz bandwidth oscilloscope to supplement the existing on-site equipment (Jerrold 900A, grid dip meter, attenuators and adapters).

3. Indicator Interface
No changes are indicated.

5.3 CURRENT CORRECTIVE ACTION PROGRAMS

The following programs are currently (February 1973) being conducted to remedy ASDE-2 deficiencies:

1. A solid state duplexer, developed as early as 1964[1] has been installed in the majority of ASDE-2 sites.

2. TSC has designed and tested a modification to the ASDE-2 modulator. Tests indicate a six to ten times improvement in modulator reliability. An electronic equipment modification procedure has been completed and approved.

3. TSC has designed a modification to correct the local oscillator and AFC reliability problems. An electronic equipment modification procedure has been completed and approved.

4. A program is also underway to develop a high resolution bright scan converted display for use with the ASDE-2.

---

(1) Evaluation of SFD-315 magnetron and solid state duplexer for ASDE-2, October 1965, Federal Aviation Agency, SRDS, Atlantic City, New Jersey.

5.4 ACTION PROGRAMS REQUIRED

Action is required in the following areas to increase reliability and to restore adequate performance to the ASDE-2's:

1. Adapt the modulator modifications as designed by TSC.

2. Analyze and test the ASDE-2 antenna and radome to determine its ICR and azimuth beamwidth.

3. Improve gain and bandwidth of receiver IF amplifiers by implementing the test and alignment procedures and by providing adequate test equipment for on-site maintenance personnel.

4. Improve bandwidth of video amplifiers by developing the modifications recommended in section 3.